MINISTRY OF THE ENVIRONMENT
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AN INTERIM REPORT ON THE PHOSPHORUS REMOVAL ACTIVITIES OF THE RESEARCH BRANCH MINISTRY OF THE ENVIRONMENT

RESEARCH BRANCH
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1 Introduction

The Ministry of the Environment has been undertaking research into phosphorus removal processes since 1963. The original research was directed towards the utilization of phosphorus by algae and subsequent harvesting of algal growth. However, our climatic conditions led to inconsistent removals and efforts were turned to chemical processes.

Initial laboratory investigations involving the use of aluminum, calcium and iron indicated lime to be an economical chemical for possible widespread application of phosphorus removal throughout the Province, therefore, the Ministry of the Environment concentrated its early efforts on lime addition to raw sewage as an effective and economical means of phosphorus removal. This was predicated upon the availability of large quantities of low-cost lime in Ontario. Results of extensive model studies led to the Ministry's first plant-scale studies at Richmond Hill. After completion of these studies, the Provinces's first full-scale permanent phosphorus removal facility was installed at the Ministry's Town of Newmarket/Township of East Gwillimbury plant. This facility employing the lime treatment principle has been operating since March, 1971.

In order to further assess the effectiveness of alum, ferric chloride and lime for use in Ontario, temporary full-scale phosphorus removal facilities are being installed in a number of plants. These studies, initiated in the spring of 1971, run through a minimum period of six months. Each involves the use of different chemical or point of chemical dosage in conventional and modified activated sludge processes.

A full range of parameters, including digester operation are being assessed. Early results of these studies indicate that all three chemicals can be successfully used in Ontario, the general criteria being the choice of the most economical one in terms of operating and capital costs.

Although the bulk of the work has involved phosphorus removal through chemical precipitation and coagulation within the standard activated sludge system other studies have been carried out involving phosphorus removal within waste stabilization ponds, aerated lagoons, in a physical-chemical system and also enhanced phosphorus removal within a conventional activated sludge system through process modifications only.

The intent of these long-term studies is to confirm design criteria and improve on methods of treatment. Results of the Ministry's studies will have general application and are intended to minimize and lower operating costs throughout the Province. In some cases, these investigations involve the re-use of industrial waste by-products. Waste pickle liquor and carbide lime are being studied for their effectiveness in removing phosphorus.

Other studies which are being carried out in conjunction with other Provincial agencies include the evaluation of the methods of treatment plants. Of prime concern are the environmental effects, fertilizer value and re-cycling potential.

At the same time as these studies are continuing, municipalities have been instructed to proceed with the assessment

of their individual phosphorus removal requirements. In Ontario, treatability studies are required at each plant to establish che-mical dosages and design parameters. These data are then used to choose the most economical chemical and the most suitable equipment to obtain the optimum removal of phosphorus at any particular plant.

The first phase of the treatability studies involves jar-testing of the plant influent and effluent using alum, ferric chloride and lime. This has, to date, been followed up in most cases where time permits with partial or full plant-scale studies to assess, under normal operating conditions, the chemical chosen from the jar-testing results as the most promising for that particular sewage. The jar-testing studies extend over a period of three weeks with the full-scale studies being a minimum of eight weeks in duration.

It is recognized that phosphorus removal alone may not be sufficient in some areas of Ontario to control eutrophication. For this reason, laboratory studies are continuing on methods of carbon and nitrogen removal which may be necessary in isolated instances as a follow-up to phosphorus removal.

It is the purpose of this paper to present a summary of the current efforts of the Research Branch of Ministry of the Environment in the field of phosphorus removal. As this is an interim report, future up-grading of the information contained in this report will be required.

This report will be divided into eight parts. Part A will deal with the Newmarket/East Gwillimbury permanent full-scale

phosphorus removal installation.

Part B is the summary of data collected from sixteen separate temporary full-scale investigations of phosphorus removal by chemical addition to existing sewage treatment plants.

Part C is the summary of data collected from the investigation of the physical-chemical process for phosphorus removal.

Part D involves chemical addition to a waste stabilization pond for phosphorus removal.

Part E involves the addition of chemicals to an aerated lagoon for phosphorus removal.

Part F involves the land disposal of waste stabilization pond effluent through spray irrigation.

Part G is a summary of a study involving the enhanced removal of phosphorus within a conventional activated sludge plant.

Part H describes a study involving the removal of phosphorus from a seasonal retention lagoon through chemical application to its surface.

2 Phosphorus Removal Investigations

Part A - Full-Scale Permanent Installation

The Newmarket/East Gwillimbury WPCP is of the conventional activated sludge design with a design capacity of 2.0 MIGPD (9080 m^3/day). Although the average daily flow during 1970 was only 79% of the plant design capacity, the flow from combined sewers often exceeds twice the design capacity during periods of heavy rainfall. The raw waste is primarily residential sewage with a minor contribution from local industries.

Phosphorus removal is accomplished by the introduction of 200 mg/l of high-grade hydrated lime to a rapid mix tank located just prior to the primary clarifiers. Lime storage, feeding and mixing facilities were installed such that hydrated lime may be received in bulk load quantities and is fed as a 25% slurry at a rate automatically controlled by the flow to the plant.

(1) Load Data

Design population	19,200
Sewage flow	1.58 MIGPD
Primary Clarifier	
Detention	2 hrs.
Loading	875 gal/day/ft^2
Aeration Process	
Detention	6.66 hrs.
Loading	18.7 lb BOD/day/1000 ft^3
Final Clarifier	
Detention	3 hrs.
Loading	664 gal/day/ft^2

(2) Performance Data

The following are the performance data of the full-scale permanent phosphorus removal facility based on the results of 3 1/2 months lime addition at 200 mg/l as $Ca(OH)_2$.

	Raw Sewage	Primary Effluent	Final Effluent
BOD (mg/l)	210	90	12
Phosphorus (mg/l)	10.7	2.2	2.1
Suspended Solids (mg/l)	380	85	9
Kjeldahl Nitrogen (mg/l)	40	32	2.4
Nitrate Nitrogen (mg/l)	trace	trace	25
Coliform Bacteria/100 ml	-	10	-

(3) Cost Data

The following cost data are based on a plant of the 2.0 MIGPD (9080 m^3/day) capacity.

a) Capital Cost

(i) Conventional plant (1963) $800,954.78
or $ 41.60/capita

(ii) Phosphorus removal facility (1971) $ 68,780.00
or $ 3.57/capita

b) Operating cost

(i) Conventional Plant (1970) $ 61,387.83

or $ 3.19/capita

(ii) Phosphorus removal facility (1971)

Chemical (96% pure hydrated lime at 200 mg/l)	$	0.94/capita/yr.
Power (additional 16 HP for lime process with a reduction of 45 HP in aeration equipment)		
- no net increase in power costs		
Labour (1 operator - $8000/yr.)	$	0.42/capita/yr.
Sludge Disposal * (liquid haulage of 10% sludge)		
- no net increase in sludge disposal costs.		
Total operating	$	1.36/capita/yr.

* Note: Sludge may also be dewatered by centrifugation to a solids content of 25 to 30% at a polymer cost of about $1.20 per ton of dried solids.

<u>Part B - Temporary Full-Scale Investigations</u>

Sixteen temporary full-scale plants have been operated for time periods ranging from 2 months to 6 months to determine the effect of alum, iron salts, and lime on the activated sludge process, its modifications, and associated equipment. This section summarizes the performance data from these temporary full-scale installations.

The chemical dosages shown in Table B-1 are those actually used in the full-scale studies and found to be effective in providing 80% total phosphorus removal with a high degree of

Table B-1

(1) BACKGROUND DATA

	ALUM		IRON SALTS		LIME	
	Range of Values		Range of Values		Range of Values	
	Min.	Max.	Min.	Max.	Min.	Max.
Population Served	250	33,000	250	15,160	1,800	33,000
BOD (mg/l)	60	435	140	550	114	453
Nitrogen (mg/l)	14	22	10	38	20	35
Phosphorus (mg/l)	6	17	7	17	9	10.7
Suspended Solids (mg/l)	120	870	150	955	91	290

Table B-1 (cont'd)

(2) LOAD DATA

	ALUM*		IRON SALTS**		LIME***	
	Range of Values		Range of Values		Range of Values	
	Min.	Max.	Min.	Max.	Min.	Max.
Flow (gal/day)	25,000	3×10^6	25,000	1.4×10^6	180,000	2.9×10^6
Retention						
Primary Clarifier (hrs)	2	2.9	3	7	1.68	3.9
Aeration (hrs)	2.13	24	4.5	11.8	2.2	13.9
BOD Loading (lb BOD/1000 ft^3/day)	4.48	95	10	4.4	51	78
(F/M lb BOD/lb MLSS/day)	0.02	0.34	0.026	0.8	0.068	0.72
Overflow Rate						
Primary Clarifier (gal/day/ft^2)	520	700	350	970	235	585
Secondary Clarifier (gal/day/ft^2)	230	445	230	750	170	600
Chemical Dosage (mg/l)	50	150	10	20	125	300

* Dosage as $Al_2(SO_4)_3^{-2} \cdot 14H_2O$

** Dosage as Fe^{+3}

*** Dosage as $Ca(OH)_2$

Table B-1 (cont'd)

(3) PERFORMANCE DATA

EFFLUENT	ALUM Range of Values Min.	Max.	IRON SALTS Range of Values Min.	Max.	LIME Range of Values Min.	Max.
BOD (mg/l)	7	25	14	25	5	105
Nitrogen (mg/l)	15	17	8	25	14	18
Phosphorus (mg/l)	0.6	1.6	1.0	2.6	0.9	2.6
Suspended Solids (mg/l)	11	55	23	32	5	97

(4) COST DATA (Chemical)

	ALUM		IRON SALTS		LIME	
F.O.B. Works (dry basis)	$45/ton		4¢ U.S./lb		$14/ton	
Delivered Cost (dry basis)	$57/ton	$70.ton	6.3¢/lb $FeCl_3$	9.2¢/lb $FeCl_3$	$21/ton	$26/ton
Actual ($/capita/year)	0.62	1.82	0.73	1.82	0.54	1.25

consistency (80% of the time). These chemical dosages were used because based on jar tests on that specific sewage it was concluded that this chemical at a particular dosage would be the most economical chemical to provide the required phosphorus removal. As a result the table shows the probable economic dosage range rather than the range of dosages found effective in providing the desired phosphorus removal. Table B-2 shows the chemical dosage range normally encountered when conducting jar test studies.

Table B-2

Jar Test Chemical Dosage mg/l
to Effect 80% Total Phosphorus Removal

Alum		Iron Salts as Fe		Lime	
Min.	Max.	Min.	Max.	Min.	Max.
50	250	10	35	100	300

The various processes and their responses to chemical addition are discussed below.

A. Conventional Activated Sludge

(1) Alum and Iron Salts

Both these chemicals have been added satisfactorily to the primary clarifiers or to the discharge of the aeration tank. Effective phosphorus precipitation has been obtained in both modes of operation. No significant change in effluent BOD and SS quality was observed.

In order to settle the chemical flocs in the primary

clarifiers, a hydraulic load of 550-650 gal/day/sq ft should be maintained. No adverse effect however was noticed if chemical floc is carried over into the aeration tanks by hydraulic loads higher than those shown above.

More conventional hydraulic rates of 700-800 gal/day/sq ft have proven adequate in settling the chemical-biological floc in the secondary clarifiers.

The increased raw sludge production associated with the chemical addition has generally been less than a 50% increase and normally is in the 35% range with alum addition to the raw sewage. The use of iron salts and the addition of the chemicals of the aeration tank discharge both result in a smaller sludge production than that mentioned above. However, a minimum of 20% increase in volatile solids loading should generally be anticipated. The raw sludge concentration frequently does not change significantly.

(2) Lime Addition

The addition of lime to the raw sewage and subsequent precipitation of the phosphorus in the primary clarifiers has been carried out at four WPCP's. In all cases the activated sludge has had sufficient natural buffering capacity to neutralize the high pH (9.5-10) of the primary effluent. In one case however when the aeration tank retention time was reduced to 2.2 hours and the F/M ration increased to 0.5 lb BOD/lb MLSS/day, the aeration tank pH rose to 9.3 as the natural buffering capacity was exceeded. Under these conditions the oxygen demand of the system dropped markedly indicating a reduced biological activity.

Since the high pH associated with the lime addition is essential to the precipitation of phosphorus (at normal Ca^{++} levels) lime cannot be used to remove phosphorus in the discharge of the aeration tank.

The lime-phosphorus floc can be settled at hydraulic rates of 800-1200 gal/day/sq ft. If chemical floc carryover is experienced however, resolubilization of the phosphorus will occur in the more neutral pH found in the aeration tank.

The raw sludge production is normal in terms of volume but higher (20-60%) in terms of lb of solids/day.

B. Contact Stabilization

Ferric chloride addition to the discharge of the contact tank has been carried out for a period of 2 months. A marked improvement in final effluent BOD and SS was found. The plant normally produced a highly variable effluent quality averaging 25 mg/l BOD and 35 mg/l SS. During the period of the study the average final effluent values were 10 mg/l BOD and 12 mg/l SS. In addition an excess of 85% total phosphorus removal was obtained.

C. Oxidation Ditch

Both alum and ferric chloride were used to precipitate the phosphorus in the raw sewage just prior to entering the oxidation ditch. Since there are no primary clarifiers at this facility,the chemical floc was removed in the secondary clarifier.

A small amount of localized sludge deposition existed in the oxidation ditch prior to the start of the programme. No

additional sludge deposition occurred in either phase of the study. In both cases adequate total phosphorus removal was obtained with no deterioration in final effluent BOD or SS values.

D. Sludge Handling

No difficulty was experienced with mechanical handling of any of the chemical sludges. Some problem was experienced with temporary organic overloading of the anaerobic digesters resulting in excessive foaming when using alum as the chemical precipitant. This has not however been a universal problem but rather a specific localized one.

Phosphorus release from alum or ferric sludges under anaerobic digestion has not been experienced, in fact the soluble phosphorus levels frequently drop to less than 1.0 mg/l in the digester contents.

The operation of a vacuum filter on raw undigested chemical sludges precipitated with alum and lime in a primary clarifier has been investigated. The alum sludge required 25% additional conditioning chemicals (on a \$/ton basis) above the normal raw sludge requirements but there was a 20% reduction in filter output in terms of lb solids/ft^2/hr. The lime sludge however required 25% less conditioning chemical (on a \$/ton basis) but increased the filter yield by 30%.

Under aerobic digestion conditions, iron sludge showed no release of phosphorus and did not inhibit sludge stabilization.

Part C - Physical-Chemical Process

Two studies are reported under this section. The first involved a prototype of a physical-chemical process not yet available on the market. The second deals with a full-scale physical-chemical process still in operation treating the sewage from Bala in the District Municipality of Muskoka.

The prototype physical-chemical unit tested in the laboratory consisted of an aerated storage tank, chemical feed and mixing apparatus, moving filter sludge separator, and effluent chlorination chamber. The unit is intended primarily for shipboard treatment of sewage before discharge.

(1) Load Data

Flow of Raw Sewage (reaction vessel)	6.2 gal/cu ft/day
BOD	10.6 lb/1000 cu ft/day
No. person eqivalents served	33

(2) Performance Data

	Influent	Effluent
P (mg/l)	12.7	2.4
BOD (mg/l)	170	26
SS (mg/l)	270	24

(3) Cost Data

3 (a) Capital: Approximately $10,000 = $ 300/capita

3 (b) Operating:

Power: \$200/year = \$6/capita

Chemicals (aluminum chlorhydrate waste product):

\$400/year (1970) = \$12/capita/year

Labour: 100 man-hours per year = \$3000/year
= \$90/capita/year

Total Operating = \$108/capita/year

The full-scale installation involves an under-drained sand filter and a portable chemical treatment plant consisting of a rapid mix tank, flocculation tank and settling tank equipped with tube settlers. The chemical used in the chemical treatment plant is hydrated lime fed as a slurry at a dosage of 200 mg/l as $Ca(OH)_2$. The following tables deal only with the chemical treatment unit.

(1) Plant Data

Flow of raw sewage	15,000 IGPD
Detention	3.5 min. rapid mix
	13 min. flocculation
	40 min. settling

(2) Performance Data

	Influent	Effluent
P (mg/l)	2.8	0.29
BOD (mg/l)	9	4
SS (mg/l)	18	5

Part D - Chemical Addition to Waste Stabilization Ponds

This section deals with information obtained from two studies. No. 1 was a two phase pilot scale study of a continuous discharge WSP to which hydrated lime was fed at a concentration of 200 mg/l during one phase, and alum was fed at a concentration of 200 mg/l during the second phase. In both cases, the chemical was mixed with the raw sewage just prior to its discharge into the lagoon.

Study No. 2 involves a full-scale continuous discharge WSP to which 200 mg/l of alum is added to the raw sewage influent pipe. The sewage is primarily domestic in origin. The design population of the WSP is 750.

(1) Load Data

1.1 Pilot Scale Study

Flow	0.675	$gal/ft^2/day$
BOD load	0.12	lb/1000 cu ft/day
Detention	30	days
Chemical Feed Dosage a)	200 mg/l lime	
b)	200 mg/l alum	

1.2 Full-Scale Study (Continuous Discharge WSP)

Surface area	6.6	acres
Flow	0.2	$gal/ft^2/day$
BOD load	8.25	lb/acre/day
Chemical Feed Dosage	200	mg/l alum

Table D-1*

Average Performance Data For Shelburne WSP

Month	Raw Sewage BOD	Raw Sewage SS	Raw Sewage Tot. P	Effluent From Cell With Alum Dosed Inf[I] BOD	Effluent From Cell With Alum Dosed Inf[I] SS	Effluent From Cell With Alum Dosed Inf[I] P_T	Effluent From Control Cell BOD	Effluent From Control Cell SS	Effluent From Control Cell Tot. P
June	118	151	107	26	40	3.5	42	30	4.5
July	295	250	15.2	36	58	3.4	49	70	4.0
August	272	466	13.5	38	145	2.6	41	68	2.5
September	185	173	16.0	29	45	2.9	38	63	5.0
October	140	190	11.1	34	41	2.8	40	41	5.9
November	120	147	9.9	43	73	2.3	45	53	4.0
December	165	290	12.5	24	35	2.0	24	37	5.6

* All units are mg/l

(2) Performance Data

2.1 Pilot Scale Study

	Raw Sewage	Effluent (Alum Add$^{\underline{n}}$)	Effluent (Lime Add$^{\underline{n}}$)
BOD (mg/l)	150	60	70
P (mg/l)*	10.0	1.5	4.5

* NOTE: In both chemical feed cases, the effluent phosphorus concentration dropped off to the above minimum level after about 40 days or 1 1/4 theoretical detention periods. The effluent Phosphorus then increased gradually to 4.5 and 1.5 mg/l for lime and alum, respectively after 80 days.

Effluent BOD was high due to the short detention time and high loading to the pilot scale waste stabilization ponds. Aluminum sulphate was more effective in reducing the phosphorus content although the alum sludge settled considerably more poorly than the lime sludge.

2.2 Full-Scale Study

Alum was found to be a more effective precipitant of phosphorus in the raw sewage influent than lime (>300 mg/l) and ferric chloride (>120 mg/l). The optimum concentration (150 - 200 gm/l) of alum is presently being directly injected into the stabilization pond influent pipe. Turbulent conditions (N_{RE} = 26,000) permit adequate mixing within the feed pipe.

Analyses of influent and effluent quality are being collected and compared to control. Table D-1 gives average monthly average data from June to December.

(3) Cost Data - Full-Scale nutrient removal supplement to existing system.

(a) Capital Cost

Storage and Feeding equipment		$	1,950.00
	or	$	1.30/capita

(b) Operating Cost

Chemical (Dry aluminum sulphate)		$	2,200.00/year
	or	$	1.50/capita/year
Labour (100 man hours/year)		$	300.00/year
	or	$	0.20/capita/year
Total Operating Cost		$	1.70/capita/year

Part E - Chemical Addition to Aerated Lagoons

The aerated lagoon at which this study was carried out serves a small town with some seasonal industry but with separated sewers. This aerated lagoon serves a population of 1,000 people.

Shortly after the beginning of the study in August 1971, sewage flow and organic strength increased due to the seasonal industrial load. An attempt was made to improve the poor phosphorus removal efficiencies by increasing the alum dose from

110 mg/l to 135 mg/l and finally to 200 mg/l. While soluble phosphorus removals at this dosage are in excess of 90%, the total phosphorus removal is approximately 60%. Results from jar tests indicated that an improvement in flocculation and hence total phosphorus removals could be achieved by the addition of polyelectrolytes. Preparations are now being made to feed a polyelectrolyte at a dose of 1 mg/l while maintaining the alum dose at 200 mg/l.

(1) Load Data

Sewage Flow	0.12	MGD
Aeration Process		
Detention	10	days
Loading	2.7	lb BOD/1000 ft^3/day

(2) Performance Data

	Influent	Effluent
P (mg/l)	5.4	2.7
BOD (mg/l)	444	118
SS (mg/l)	307	73

(3) Cost Data

Chemical Cost (49% active $Al_2SO_4)_3 \cdot 14H_2O$) $1326.00/year

or $ 1.32/capita/year

Part F - Land Disposal of Waste Stabilization Pond Effluent

In this study, the effluent from a waste stabilization pond with an almost purely domestic sewage influent is being spray irrigated onto adjacent land. This WSP is similar to that described in Part D, but without the chemical addition.

Background Data

Design population	750
Irrigation Water	
BOD (mg/l)	42
SS (mg/l)	60
Phosphorus (mg/l)	3.8

(1) Load Data

Loading Rate	62,400 gal/acre/day
BOD load	3.68 lb/acre/day

(2) Performance Data

Soil in the land disposal site is a well-drained fine sandy loam with moderate permeability estimated to be 1.5 to 5 cm per hour. Although results of this study are not yet available due to its short period of operation, similar studies with this type of soil (Penn. State U., Study No. 23) indicated that a high degree of P removal will be achieved, but an increase in nitrate nitrogen in the percolate did, however, occur.

During this study, to date, surface lysimeters in both grassed areas have shown a 95% removal of total phosphorus, 80% removal of Kjeldahl Nitrogen and 99% removal of nitrites present in the effluent. Nitrate levels have been insignificant.

(3) Cost Data (Spray Irrigation)

(a) Capital Cost

These costs include a 15 HP centrifugal pump, 305 meters of 10 cm Aluminum main pipe, 1410 meters of 5 cm polyethylene lateral pipe and 60 pulsating sprinklers.

	-	\$7,000.00
	or	\$ 10.00/capita
	or	\$ 720.00/acre

(b) Operating Cost (Spray Irrigation)

Power		26.4×10^3 KW hrs/yr.
	or	\$ 350.00/year
	or	0.23/capita/year

Part G - Enhanced Phosphorus Removal

To investigate the enhanced biological removal of phosphorus from sewage, studies were carried out using modified activated sludge treatment systems to help define design and operational characteristics required to increase the P removal efficiency in hard water sewage without the use of chemicals. Laboratory-scale studies using settled domestic sewage showed that modifications

in the hydraulic characteristics and air supply rates were effective in improving P removal. Two hydraulic characteristic modifications, fill-and-draw (plug flow) and cascading, were studied. The cascade arrangement was unsuccessful. In the fill-and-draw units carbon was supplemented at two levels increasing the influent BOD from 157 mg/l to 239 and 491 mg/l, respectively. Waste sludges produced from the plug flow system contained between 5 and 9.2% P on a volatile suspended solids (VSS) dry weight compared to 2 - 3% P content in sludges from conventional activated sludge processes. Effluent P concentrations were reduced to 2.5 - 7.5 ppm compared to 6 - 14 ppm before the modifications were incorporated.

(1) Load Data

Aeration Process

Flow	25 gal/cu ft/day
Loading	75 - 200 lb BOD/1000 cu ft/day
	0.25 - 0.50 lb BOD/lb MLSS/day
Retention	2.5 - 3 hours
BOD/P ratio	Design range 14/1 to 25/1
Sludge return rate	20 - 40% of plant flow

(2) Performance Data (Laboratory-scale test units treating settled domestic sewage)

Performance data of the fill-and-draw system are presented in Table G-1, while performance data for the carbon supplemented system are provided in Table G-2.

<u>Sludge Production</u> - Fill-and-Draw Unit averaged approximately 0.8 lb VSS produced per lb BOD removed.

- Fill-and-Draw Carbon Supplemented Units averaged approximately 0.6 and 0.67 lb VSS produced per lb BOD removed respectively.

<u>P Content of Waste-Sludge</u> - Fill-and-Draw Unit averaged 6.1 lb P (5 - 9.2 range) per 100 lb VSS (dry weight basis).

- Fill-and-Draw Carbon Supplemented Units averaged 3.7 lb and 4.4 lb P per 100 lb VSS (dry weight basis) respectively.

(3) Cost Data

The added cost for implementing enhanced biological P removal at a conventional activated sludge plant would include the expense necessary to prevent recycle of soluble P compounds released during sludge handling operations and the expense for providing adequate aeration capacity and aeration tank modifications. However, no estimate of cost for this method of P removal is presented because the handling of waste sludge, and digester supernatant where applicable, is closely related to existing plant facilities. Also, the cost of increasing the air supply rate depends primarily on existing aeration capacity. The costs for the increased air supply would be approximately twice the average costs normally experienced.

Table G-1

Average Performance Data for
Fill-and-Draw System

Parameter	Average Concentration Mg/l Settled Sewage	
	Influent	Effluent
pH	7.6	7.6
BOD	157	15
Total P	12.1	6.9
Ortho P	6.8	5.5
Free NH_3	29	3.2
Total Kj	44	5.1
NO_3^-N	1	21.6
SS	109	15
COD	336	54
TOC	128	10
TC	210	63

* Except pH

Table G-2

Average Performance Data for
Fill-and-Draw Carbon Supplemented System

Parameter	Average Concentration mg/l* Settled Sewage	
	Influent	Effluent
1 st Run		
pH	6.1	7.2
BOD	491	26
Total P	13	6.4
Ortho P	5.5	3.8
Free NH_3	27	5.4
Total Kj	55	9.7
NO_3 -N	41	11.2
SS	161	17.5
COD	832	92
TOC	222	24
TC	295	57
2 nd Run		
pH	7.6	8.0
BOD	239	9.4
Total P	10	4.5
Ortho P	4.5	3.8
Free NH_3	23	0.7
Total Kj	37	2.9
NO_3 -N	41	10.8
SS	106	7.3
COD	450	52
TOC	149	18
TC	219	54

* Except pH

Prior to going into full-scale studies into enhanced biological P removal through the activated sludge process, background data was collected at several Municipal WPCP's. Eleven activated sludge plants studied achieve P reductions of 58-85% during treatment of domestic sewage and mixed domestic-industrial wastes.

The P uptake by the sludge at some of these plants may be attributable to a combination of biological and precipitation reactions. Two of the plant studied that achieve high P reduction receive inorganic industrial wastes high in aluminum, calcium and iron salts. If the character of the raw sewage were changed significantly through pretreatment of the industrial wastes, the abnormally high P reductions now being achieved would perhaps be reduced. Conversely, many industrial wastes containing the correct cations that are effective in the removal or ortho and organic forms of P and that are now pre-treated could be more effectively fed into the activated sludge process. This would include the controlled addition of carbohydrate matter to waste waters such as from brewery wastes, to increase the BOD/P ratio. In the enhanced phosphorus removal process the vehicle for disposal of the P is the waste activated sludge. Because the waste sludge releases P under anaerobic conditions, rapid removal of settled sludge from the secondary clarifiers is essential. This can be accomplished by frequent or continuous mechanical action or suction of the settled sludge, or by froth flotation applied directly to the aeration basin.

Anaerobic digester supernatant and the waste activated sludge are rich in P compounds. To prevent the recycle of redissolved

precipitated P compounds back to the system, waste sludge and digester supernatant cannot be discharged into the primary clarifiers but must be treated separately from the activated sludge system.

The abnormally high P removals obtained during the laboratory studies indicate that enhanced P removal by the activated sludge process is accomplished in the aeration tank by incorporation with the sludge solids. Based on reports by others and on data obtained during the laboratory studies which indicated that enhanced removal of P is dependent on aeration detention time, the decision was made to investigate five existing conventional activated sludge plants, using a 20% Rhodamine WT tracer dye, to determine the hydraulic characteristics of the aeration tanks. The results of the dye tracer studies conducted at two existing plants indicate hydraulic conditions approaching plug flow with modal detention times greater than 70 percent of the theoretical displacement time. With minor physical and operational modifications to the activated sludge process, these plants might be adapted to significantly increase their P removal effectiveness without chemical addition costs, provided that adequate aeration capacity is available to satisfy a higher operating dissolved oxygen concentration requirement for the process.

Part H - Chemical Dosing of Retention Lagoons

The three-celled lagoon at Arthur, Ontario was chosen to study the batch chemical treatment for phosphorus removal in a typical fill-and-draw lagoon. Three cells, (two 5 acres and one 7.5 acres) are operated in parallel, are below design capacity, do not have unusual industrial waste problems, and have a critical receiving stream.

Alum and sodium aluminate were chosen as the most promising chemical precipitants and were tested extensively in jar tests, using ten-litre samples, and in "in-situ" studies, using 1800 l. cylinders.

Both the jar tests and in-situ studies indicated that alum was more efficient than straight sodium aluminate or a mixture of the two. Alum dosages of 250-300 mg/l were required to achieve 80% removal of the phosphorus (control levels of total phosphorus ranged from 6.8 - 7.8 mg/l) and dosages of 275 - 300 mg/l were required to reduce the total phosphorus below 1.0 mg/l. However, in the large cylinders a few days after treatment there was usually an increase of 0.5 mg/l in the total phosphorus, presumably released from the precipitate.

On the basis of these results a field trial was undertaken in one of the 5 acre lagoons in early December, 1971. A single dose of 325 mg/l should have reduced the total phosphorus to between 0.5 and 1.0 mg/l. The 47,500 lb. of liquid alum was applied by two outboard motor boats in approximately 5 hours.

By the following day the Secchi disc reading had increased from 8 inches to 5 feet and the total phosphorus was reduced to 0.1 mg/l. This was a 98.9% removal of phosphorus, much better than the preliminary tests indicated. The fecal coliforms and coliform bacteria had decreased by 97% respectively.

Twenty-four hours after treatment, draining of the lagoon was begun and it was completed in 5 days, leaving 2 ft. of water remaining in the lagoon. During the next two months there was no inflow into the lagoon and frequent monitoring indicated that there was no substancial release of phosphorus since it reached a maximum of only 0.4 mg/l during this time.

Thus far this method appears very promising, giving reasonably easy application, excellent effluent quality, and apparently relatively little phosphorus release from the sediments. However, during an enclosure study in September at the Listowel lagoon, the alum treatment appeared to enhance a blue-green algae bloom two weeks after the application. This aspect will require further study.

Jar tests using alum, lime and ferric chloride on water from many other fill-and-draw lagoons in Southern Ontario are now underway and appear to indicate that alum is again the most efficient chemical and that dosages of 100-150 mg/l remove over 80% of the total phosphorus.

3 General Observations

The following are general observations made during the progress of the various phosphorus removal investigations. They are presented as references for the engineer responsible for the design of any phosphorus removal facility.

From the studies carried out to date by the Research Branch it appears that all existing sewage treatment processes may be readily adapted with some form of chemical treatment for phosphorus removal. In the primary process, the prime coagulant is added to the raw sewage/primary clarifier. In the conventional activated sludge process depending upon the coagulant used, it may be added to either the raw sewage/primary clarifier or directly into the aeration tank. In the extended aeration modification either alum or iron salts may be added directly to the discharge of the aeration process. In all of its full-scale investigations to date, the Research Branch has not found the need to add the coagulant as a tertiary stage.

Studies to date indicate that when lime is being added to the raw sewage for phosphorus removal, hydraulic loadings across the primary clarifier can be increased significantly. However, with alum and iron salt addition, conventional clarifier loading rates should be adhered to.

The prime considerations in chemical addition improving cost performance relationships is limited to the additional BOD and SS removal attained when phosphorus removal is effected in the primary clarifier. These increased organic removals can result in reduced aeration horse-power and tankage. Present indications are that chemical dosages for phosphorus removal frequently are

independent of point of application within a treatment plant, i.e. primary, aeration, or tertiary.

Sewage quality, characteristics, and the presence of industrial wastes necessitates the need for conducting jar tests to determine both effective and optimum chemical dosages for phosphorus removal. Presently a prediction, from sewage characteristics alone, of what chemicals will or will not effect suitable phosphorus removal cannot be made.

The use of chemicals for phosphorus removal within a sewage treatment plant may result in a modification of complete change in the traditional methods of handling and disposing of sludges, especially in the case of lime.

Anaerobic digestion is foreseen as a continued practice for handling chemical sludges when alum or iron salts are used for phosphorus removal. With the addition of lime, anaerobic digestion may or may not be feasible. In one instance, digestion ceased after 60 days of operation with lime addition to the raw sewage but the pH of that raw chemical sludge was approximately 10.0. In another study involving lime addition the pH of the raw sludge was only 7.8 and perhaps this sludge would have been amenable to digestion.

Both alum and lime sludges were found amenable to vacuum filtration but both required sludge conditioning with ferric chloride and lime. Centrifugation of lime sludge has also been found to be quite feasible requiring the addition of approximately one pound of polymer per ton of dried solids.

The Research Branch, to date, has had little experience with substitutes for detergent phosphorus on sewage

treatment processes. Work with NTA has indicated it to have no detrimental effects while sodium metasilicate is thought to be interfering with settling in one investigation using lime.

A reduction in the phosphate content of raw sewage will result in little to no reduction in the cost of removing the remainder of the phosphorus through chemical coagulation. In the treatment of sewage with chemicals, regardless of the chemical applied, there appears to be an inherent chemical demand whether phosphorus is present or not.

In the enhanced phosphorus removal process any reduction in phosphorus content of raw sewage will improve the influent BOD/P ratio which is generally too low to provide for the complete removal of phosphorus biologically.

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